The potential role for deep groundwater pumping in the control of irrigation induced salinity in the Riverine Plain:
A case study of the Coleambally Irrigation Area

Prasad, A., Christen E.W. and Khan, S.

CSIRO Land and Water, Griffith, NSW
Technical Report 1/01, June 2001
The potential role for deep groundwater pumping in the control of irrigation induced salinity in the Riverine Plain: A case study of the Coleambally Irrigation Area

Prasad, A., Christen E.W. and Khan, S.

CSIRO Land and Water
PMB No 3
Griffith NSW 2680
(02) 69601500

Technical Report 1/01

June 2001

Citation Details:

Copies of this report available from:
Publications or Information
CSIRO Land and Water
GPO Box 1666
Canberra, ACT 2601
Summary

This report describes a study undertaken to explore the feasibility of deep groundwater pumping in the Riverine plain for salinity control and conjunctive water use. In the Riverine plain water quality in the shallow aquifers is generally poor and extremely variable, 1 dS/m – 30 dS/m (1000-30,000 EC). These shallow aquifers are generally considered to be too saline with too low hydraulic conductivity to be an irrigation resource. Deep groundwaters, however, are generally of good quality, 0.5 dS/m – 0.7 dS/m (500-700 EC), in highly transmissive aquifers. Deep groundwater pumping may also serve to promote downward leakage from the upper aquifers and hence assist in surface soil salinity control. If this occurs then deep groundwater pumping can be both a resource and a surface salinity control measure. The pumped groundwater can be conjunctively used with low salinity surface water, however this requires that in the long term the deeper aquifer salinity is not increased significantly.

These factors were investigated by groundwater modeling of a case study, the Coleambally Irrigation Area (CIA), to ascertain the potential spatial and temporal impacts of long term deep groundwater pumping on the aquifer system.

The groundwater system of the CIA was modeled using a four layer MODFLOW groundwater model. Solute transport was included using the MT3D package to investigate salinity changes in the aquifers. Developing initial groundwater salinity conditions proved difficult, especially for the deeper layers, due to lack of data.

Five pumping scenarios were run for 15 years. These were either a single or two separate bores pumping a total volume of 4000 ML/year. The results from these scenarios were compared with the base scenario where there was no pumping.

The results showed that a widespread drawdown could be created in the deeper aquifers but this resulted in only small drawdowns in the shallow formations. The impact of deep pumping was widespread and the greatest impact was not necessarily at the bore site. The drawdown in the shallow layers depended upon the degree of connection between these and the deeper layers. This small amount of leakage is unlikely to have a significant impact on existing salinity problems. However,
maintaining and enhancing the current deep leakage should assist with salinity control in combination with other measures.

The distribution of the leakage across the landscape is uncertain, as the spatial connection between the deep and shallow aquifers is not well known. The deep pumping however will cause drawdowns across large areas of southern CIA and as such this will provide the opportunity for leakage to occur from the upper aquifers. The amount of leakage that will occur will depend upon the local geology and the impact it has on the sustainability of farming will depend upon many other factors.

The results of deep groundwater pumping on the shallow layers are not immediate. This means that using deep groundwater pumping to assist in salinity control is a long-term exercise, the full benefits of which will not become apparent for many years. This modeling has clearly shown this and indicates that two or three years of monitoring of deep pumping installations are not adequate to gauge the full impact.

Since deep groundwater pumping will not have an immediate effect, for adequate salinity control in the root zone and reclamation of already salinised areas, shallow groundwater pumping (Shepparton formation) is more likely to be successful. However, this has the twin difficulties of a relatively impermeable shallow formation and very saline shallow groundwater.

With deep pumping the pumped water quality is good and thus can be conjunctively used with the non saline surface supplies. The volume of water that needs to be pumped to have a widespread impact is relatively small and as such there is little difficulty in mixing the groundwater with surface water supplies to achieve a negligible increase in the supply water salinity. The deeper aquifer salinity is likely to increase only slightly due to the pumping so conjunctive use with surface water should be possible in the long-term.

Overall it it may be considered that deep groundwater pumping for salinity control in irrigation areas of the Riverine plain can be usefully used as a strategic complementary tool to other measures.
This report describes modeling for the general scientific analysis of the impact of deep pumping in the Riverine plain, in the context of conjunctive water use and salinity control. This report should not be used as an analysis of the appropriateness of deep pumping in the Coleambally Irrigation Area nor as a basis for the siting of pumps. These assessments should be undertaken by detailed site specific hydrogeological investigation.

**Acknowledgements**

We acknowledge funding from Coleambally Irrigation Cooperative Ltd. and The Australian Centre for International Agricultural Research. The help and co-operation of Dept. Land and Water Conservation, Mr. Ary van der Lelij and Mr. Scot Lawson, and Coleambally Irrigation Cooperative Ltd., Mr. Arun Tiwari and Ms Karen Maher, in making available data and reference material is highly appreciated.
# TABLE OF CONTENTS

1 INTRODUCTION 1

2 BACKGROUND 3
   2.1 The Coleambally Irrigation Area (CIA) 3
   2.2 Regional hydrogeology 5
      2.2.1 Renmark group 6
      2.2.2 Calivil formation 7
      2.2.3 Shepparton formation 7

3 REGIONAL GROUNDWATER MODEL 8
   3.1 Recalibration of the CIA model 11
   3.2 Solute transport model development 13
      3.2.1 Salinity data collection and analysis 14
      3.2.2 Boundary and initial conditions for the solute transport model 23
      3.2.3 Solute transport model parameters 27
      3.2.4 Solute transport model run, calibration and sensibility study 28
   3.3 Pumping scenarios 38

4 MODELING RESULTS 42
   4.1 Scenario 1 43
   4.2 Scenario 2 44
   4.3 Scenario 3 51
   4.4 Scenario 4 56
   4.5 Scenario 5 57
   4.6 Scenario 6 64

5 DISCUSSION 66
   5.1 US drawdowns 66
   5.2 Groundwater salinity 70
   5.3 Aquifer salinity 70

6 CONCLUSIONS 73

7 REFERENCES 75
LIST OF FIGURES

Figure 1. Location of Coleambally Irrigation Area.................................................................................... 3
Figure 2. Depth to watertable (m) in the CIA, September 1999 .............................................................. 4
Figure 3. East to west transect through Northing 6149562 m.............................................................. 6
Figure 4. CIA groundwater model description......................................................................................... 8
Figure 5. Observed and calculated hydrographs: Piezometer GW030349_1 Model Layer = Upper Shepparton. Piezometer location = Easting 383100(m) Northing 6176150(m)........................... 10
Figure 6. Observed and calculated hydrographs: Piezometer GW030389_2 Model Layer = Renmark. Piezometer location = Easting 416487(m) Northing 6167017(m) ............................................... 10
Figure 7. Piezometer GW030341_1, Calivil Layer...................................................................................... 12
Figure 8. Piezometer GW030489_2, Calivil Layer...................................................................................... 12
Figure 9. Piezometer GW036366_2, Calivil Layer...................................................................................... 12
Figure 10. Piezometer GW030282_2 Layer Calivil.................................................................................... 13
Figure 11. Piezometer GW036040_2 Layer Calivil.................................................................................... 13
Figure 12. Piezometer GW036367_2 Layer Calivil.................................................................................... 13
Figure 13. Salinity (EC) in US 1973 .................................................................................................. ........... 15
Figure 14. Salinity (EC) in US 1978 .................................................................................................. ........... 16
Figure 15. Salinity (EC) in US 1983 .................................................................................................. ........... 16
Figure 16. Salinity (EC) in US 1984 .................................................................................................. ........... 16
Figure 17. Salinity (EC) in US 1987 .................................................................................................. ........... 17
Figure 18. Salinity (EC) in LS 1973 .................................................................................................. ........... 17
Figure 19. Salinity (EC) in LS 1978 .................................................................................................. ........... 18
Figure 20. Salinity (EC) in LS 1984 .................................................................................................. ........... 18
Figure 21. Salinity (EC) in LS 1987 .................................................................................................. ........... 18
Figure 22. Salinity (EC) in Calivil 1976 ............................................................................................. .......... 19
Figure 23. Salinity (EC) in Calivil 1979 ............................................................................................. .......... 20
Figure 24. Salinity (EC) in Calivil 1982 ............................................................................................. .......... 20
Figure 25. Salinity (EC) in Calivil 1985 ............................................................................................. .......... 20
Figure 26. Salinity (EC) in Renmark 1976 ............................................................................................. ...... 21
Figure 27. Salinity (EC) in Renmark 1979 ............................................................................................. .......... 22
Figure 28. Salinity (EC) in Renmark 1982 ................................................................. 22
Figure 29. Salinity (EC) in Renmark 1985 ................................................................. 22
Figure 30. Piezometers sampled for salinity in US, 1984 ........................................ 23
Figure 31. Model initial conditions of salinity (EC) in US, 1985 ............................... 24
Figure 32. Model initial conditions of salinity (EC) in LS, 1985 ............................... 24
Figure 33. Piezometers sampled for salinity in the Calivil, 1985 ............................... 25
Figure 34. Salinity data (EC) for the Calivil with one high, erroneous, value, 1995 data 25
Figure 35. Salinity (EC) data for the Calivil with the erroneous value removed, 1995 data 26
Figure 36. Model initial conditions of salinity (EC) in the Calivil, 1985 ...................... 26
Figure 37. Model initial conditions of salinity (EC) in the Renmark, 1985 .................... 27
Figure 38. Model generated salinity (EC) in the US for 1995 ..................................... 28
Figure 39. Model generated salinity (EC) in the LS for 1995 ....................................... 28
Figure 40. Model generated salinity (EC) in the Calivil for 1995 ............................... 29
Figure 41. Model generated salinity (EC) in the Renmark for 1995 ............................ 29
Figure 42. Modeled salinity difference in the US between 1985 and 1995 .................... 30
Figure 43. Modeled salinity difference in the US between 1990 and 1995 .................... 31
Figure 44. Modeled salinity difference in the LS between 1985 and 1995 .................... 32
Figure 45. Modeled salinity difference in the LS between 1990 and 1995 .................... 32
Figure 46. Modeled salinity difference in the Calivil between 1985 and 1995 ............... 33
Figure 47. Modeled salinity difference in the Calivil between 1990 and 1995 ............... 33
Figure 48. Modeled salinity difference in the Renmark between 1985 and 1995 ............. 34
Figure 49. Modeled salinity difference in the Renmark between 1990 and 1995 ............. 35
Figure 50. Salinity (EC) modeled and observed at piezometer 405, Calivil layer ............ 36
Figure 51. Salinity (EC) modeled and observed at piezometer 36040, Renmark layer .......... 36
Figure 52. Salinity (EC) modeled and observed at the Coleambally deep bore site, Renmark/Calivil layer ............................................................... 37
Figure 53. Deep bore locations in CIA ......................................................................... 39
Figure 54. Modeled temporal variation of head difference (S1-S0) in Calivil layer ............ 43
Figure 55. Modeled temporal variation of salinity (S1-S0) at the bore, location A .............. 44
Figure 56. Modeled difference in drawdown (S2-S0) in the Renmark after 5 years ............. 44
Figure 57. Modeled difference in drawdown (S2-S0) in the Renmark after 15 years................................. 45
Figure 58. Modeled difference in drawdown (S2-S0) in the Calivil after 5 years ................................. 45
Figure 59. Modeled difference in drawdown (S2-S0) in the Calivil after 15 years .............................. 46
Figure 60. Modeled temporal variation of head difference (S2-S0) in Renmark layer .............................. 46
Figure 61. Modeled temporal variation of head difference (S2-S0) in Calivil layer ................................. 47
Figure 62. Modeled difference in drawdown (S2-S0) in the LS after 5 years ...................................... 48
Figure 63. Modeled difference in drawdown (S2-S0) in the LS after 15 years ...................................... 48
Figure 64. Modeled difference in drawdown (S2-S0) in the US after 5 years .................................... 49
Figure 65. Modeled difference in drawdown (S2-S0) in the US after 15 years .................................... 49
Figure 66. Modeled temporal variation of head difference (S2-S0) in LS layer ....................................... 50
Figure 67. Modeled temporal variation of head difference (S2-S0) in US layer ........................................ 50
Figure 68. Modeled temporal variation of discharge water salinity (S2-S0) at the bore, location A .......... 51
Figure 69. Modeled difference in drawdown (S3-S0) in the Renmark after 15 years ........................... 52
Figure 70. Modeled difference in drawdown (S3-S0) in the Calivil after 15 years ............................... 52
Figure 71. Modeled temporal variation of head difference (S3-S0) in Renmark layer at the bore site ....... 53
Figure 72. Modeled temporal variation of head difference (S3-S0) in Calivil layer at the bore site .............. 54
Figure 73. Modeled difference in drawdown (S3-S0) in the LS after 15 years ....................................... 54
Figure 74. Modeled difference in drawdown (S3-S0) in the US after 15 years .................................... 55
Figure 75. Modeled temporal variation of head difference (S3-S0) in US layer at the bore site ................. 55
Figure 76. Modeled temporal variation of discharge water salinity (S3-S0) at the bore, location B ........... 56
Figure 77. Modeled temporal variation of salinity (S4-S0) at the bore, location B ................................... 57
Figure 78. Modeled difference in drawdown (S5-S0) in the Renmark after 15 years ........................... 58
Figure 79. Modeled difference in drawdown (S5-S0) in the Calivil after 15 years ............................... 58
Figure 80. Modeled temporal variation of head difference (S5-S0) in Renmark layer, location A ........... 59
Figure 81. Modeled temporal variation of head difference (S5-S0) in Calivil layer, location A ............... 59
Figure 82. Modeled temporal variation of head difference (S5-S0) in Renmark layer, location C ............ 60
Figure 83. Modeled temporal variation of head difference (S5-S0) in Calivil layer, location C ............... 60
Figure 84. Modeled difference in drawdown (S5-S0) in the LS after 15 years ............................... 61
Figure 85. Modeled difference in drawdown (S5-S0) in the US after 15 years .................................... 62
Figure 86. Modeled temporal variation of head difference (S5-S0) in US layer, location A ..................... 62
Figure 87. Modeled temporal variation of head difference (S5-S0) in US layer, location C ..................... 63
Figure 88. Modeled temporal variation of discharge water salinity (S5-S0) at the bore, location A .......... 63
Figure 89. Modeled temporal variation of discharge water salinity (S5-S0) at the bore, location C ........... 64
Figure 90. Modeled temporal variation of salinity (S6-S0) at the bore, location A ............................... 65
Figure 91. Modeled temporal variation of salinity (S6-S0) at the bore, location C ............................... 65
Figure 92. Area impacted by drawdowns in the US .............................................................................. 67
Figure 93. Extra water removed from US by deep pumping ................................................................. 68
Figure 94. Change in salinity (EC) in the Renmark layer (S5-S0) after 15 years ................................. 71
Figure 95. Change in salinity (EC) in the Calivil layer (S5-S0) after 15 years ...................................... 72

**LIST OF TABLES**

Table 1. Piezometers selected for recalibration .................................................................................. 11
Table 2. Parameters for the solute transport model ............................................................................ 27
Table 3. Bore locations ......................................................................................................................... 40
Table 4. Pumping scenarios ............................................................................................................... 41
1 Introduction

Groundwater pumping and conjunctive use of that water has been proposed as a potential method to improve the sustainability of irrigated areas. The groundwater pumping is used to drawdown watertables and hence assist salinity control of the crop root zone, whilst the pumped water is used to augment surface irrigation supplies.

The hydrogeology of the Riverine plain can be described in terms of three major stratigraphic units. The uppermost unit is the Shepparton formation where the shallow watertables in the irrigation areas are present. The Shepparton formation can be idealised as an extensive silt and clay sheet interspersed by randomly distributed interconnected sand beds (prior streams) of variable groundwater salinity. The watertable level is influenced by leakage to or from the underlying Calivil and Renmark formations, which from a regional perspective may be considered to be a single highly transmissive sand and gravel aquifer of good quality water.

Thus for the Riverine plain a conjunctive water use system would preferably be by ‘deep’ pumping of the good quality highly transmissive deep aquifers. This type of system has been explored by Lawson and Van der Lelij (1992) by monitoring the effects of a deep bore (120m) in the Coleambally Irrigation Area (CIA) on aquifer pressures. Their findings were that the bore had a limited spatial extent of drawdown in the upper layers (about 0.3 m drawdown in a 1 – 2 km radius from the bore), despite relatively large drawdowns in the deeper layers ~ 10 m. These findings were similar to those in studies undertaken in the Northern Victorian section of the Riverine plain that concluded that pumping from deep aquifers has a “muted effect on shallow watertable levels”, (Evans and Nolan, 1989). This is due to the poor conductivity of the surface Shepparton formation that restricts water flow to the deeper aquifers.

With these studies based on field monitoring it is difficult to accurately quantify the spatial impacts of the pumping because in the Riverine plain the deep aquifers have generally poor connection with the upper unconfined aquifer. However, this connection is variable with sometimes good localised connections. Thus, knowing
where there are good connections and drawdowns will occur is critical to accurately gauge the success of deep pumping in controlling shallow watertables. Another factor is that there is likely to be a damped response between changing pressures in the deep aquifers and shallow formations. Thus the full effect of pumping may not become apparent for some time after pumping has commenced.

These results have led to a general opinion that deep groundwater pumping has only a minor role to play in salinity control for the irrigation areas in the Riverine plain. However, as stated by Evans and Nolan (1989) reduction in deep aquifer pressures (or even stabilising current pressures, preventing an upward trend) has a beneficial effect on long term salinity problems by maintaining or even increasing the current downward leakage from shallow aquifers. Although this leakage is small it does provide some opportunity for downward movement, the quantitative effect of this on long term surface soil salinity is not known.

When contemplating deep groundwater pumping to assist in salinity control there is a complementary benefit of augmented surface irrigation supplies. However, any pumping must ensure that the pumped water salinity is low enough that it may be suitably mixed with the fresh surface supplies to a safe salinity. In the long term this requires that the aquifer salinity should not be increased significantly.

These factors are investigated by groundwater modeling of a case study, the Coleambally Irrigation Area, to ascertain the potential spatial and temporal impacts of long term deep groundwater pumping on the aquifer system.
2 Background

2.1 The Coleambally Irrigation Area (CIA)

The CIA is located in the Riverine Plain in the lower part of the Murrumbidgee River catchment in southeastern Australia, Figure 1. It has a semi-arid climate with annual rainfall of around 400-450 mm. The CIA comprises an area of 79,000 ha situated between the Murrumbidgee River and Yanco creek. The area was developed between 1960 and 1973. The main irrigated enterprises in the area are rice, sheep/annual pastures, winter crops, soybeans and some horticulture. However, rice, which is grown under ponded conditions, is the major land use and also the biggest consumer of irrigation water.

Figure 1. Location of Coleambally Irrigation Area

Prior to irrigation development water tables in the area were around 15-20 m below the ground surface. Since irrigation began water levels have risen at rates of up to 1 m per year with the effect that now a large groundwater mound exists beneath the CIA. In 1999 around two thirds of the CIA had water tables within 2 m of the ground surface, Figure 2.
Rising water tables with their associated effects of water logging and soil salinisation are threatening the agricultural productivity and environmental sustainability of the area. Generally control of water tables involves measures which can reduce recharge to or can induce discharge from the groundwater. Groundwater pumping and reuse is a possible method of water table control. The groundwater system in this area is broadly classified as a shallow or unconfined system and a deep or confined system (a brief hydrogeology of the area is described in the next section). One major constraint in the groundwater use is its quality. Water quality in the shallow aquifers is extremely variable, 1 – 30 dS/m (1000-30,000 EC), and in general, shallow groundwaters are of too poor a quality to be considered as an irrigation resource. Deep groundwaters, however, are generally of good quality, 0.5 – 0.7 dS/m (500-700 EC).

Deep groundwater pumping thus may serve both as a resource and watertable/salinity control. This groundwater can be used conjunctively with the surface water to improve the environmental sustainability of the CIA.

Sustainable conjunctive water management is constrained by surface and groundwater water availability and quality. If too much water enters the groundwater
system then the land will be waterlogged, if too much water is removed from the groundwater system then the groundwater resource availability will be depleted and may be degraded by salt intrusion. The objective of sustainable conjunctive water use is to find an optimal combination of groundwater and surface water use that augments irrigation supply and also controls salinisation and waterlogging.

In order to determine sustainable levels of surface water and groundwater use at a regional scale, the response of the groundwater system to changes in recharge rates and groundwater pumping rates needs to be determined. The best method of determining how a complex groundwater system will behave under variable conditions is to model the system. The MODFLOW (McDonald and Harbaugh, 1988) model of the CIA previously developed by CSIRO (Enever, 1999) was improved by refining the calibration. Historical water salinity data were collected, collated and analyzed and a MT3D (Zheng, 1990) solute transport model was developed and included into the regional groundwater model. This combined regional groundwater and solute transport model was used to predict the response of the groundwater system to deep pumping in terms of head and salinity changes. With the constraints of acceptable drawdowns and salinity changes a number of scenarios were run to determine whether deep groundwater pumping could be used to create substantial drawdowns in the upper layers whilst maintaining acceptable deep groundwater quality.

### 2.2 Regional hydrogeology

Pels (1968) and Wooley and Williams (1978) have described the geology and geomorphology of the CIA. In related studies Brown and Stephenson (1991) have discussed the geology of the Murray basin and Evans and Kellet (1989) have described the hydrogeology of the Murrumbidgee alluvial fan, which forms the larger part of the lower Murrumbidgee region. Drury et al. (1984) and Brown (1985) have considered the stratigraphy and resource potential. Stannard (1970) describes various soil types in the area. Prathapar et al. (1997) described the regional hydrogeology of the area, which was used in the development of a regional groundwater model of the area (Enever, 1999).
The CIA is underlain by unconsolidated non-marine Tertiary and Quaternary sediments in the form of an extensively gently sloping alluvial fan with its apex near Narrandera. The thickness of the sediments increases in a westerly direction from 150 m at the eastern flank to 250 m at the western end. Based on age and type of the deposition Brown and Stephenson (1999) divided the sediments into three distinct groups namely Renmark, Calivil and Shepparton formations. A typical east-west cross-section of the aquifer system is given in Figure 3.

Figure 3. East to west transect through Northing 6149562 m

2.2.1 Renmark group

The Renmark group is the oldest stratigraphic unit and directly overlies the pre-Cainozoic bedrock. It was deposited during the Palaeocene to Middle Miocene ages. The environment of the deposition was fluvio-lacustrine in nature comprising meandering stream channels, floodplains and swamps. The Renmark group is the most extensive stratigraphic unit of the basin. It forms an almost continuous blanket over the basin bedrock. The base of the Renmark group consists of light brown or quartz sand (Warina Sand). The upper sequence consists of more argillaceous and carbonaceous sediments called Olney Formation (Brown & Stephenson 1991). It is estimated (Lawson, unpublished thesis, 1992) that 30 to 50% of the Renmark group is comprised of sand. The average horizontal hydraulic conductivity of the Renmark formation lies in the range of 10-30 m/day, but it can be as high as 100 m/day (Prathapar et al, 1997).
2.2.2 Calivil formation

Above the Renmark group lies the Calivil Formation, which was deposited during the late Miocene to early Pliocene ages in lacustrine environments. It consists of predominantly pale grey coarse to granular quartz sand, with lenses of kaolin and carbonaceous clay (Brown and Stephenson, 1991). Lawson (1992) has estimated that this formation consists of 50 - 70% sand and gravel. The average horizontal hydraulic conductivity of the Calivil formation estimated at Darlington Point is 130 m/day (Prathapar et al., 1997), however values up to 230 m/day are reported in the Victorian part of the formation (Enever, 1999).

2.2.3 Shepparton formation

The third main formation is the Shepparton Formation. It was deposited from the Pliocene age until present day. It consists of a matrix of clay, silt and silty clay, with lenses of fine to coarse sand and gravel. The clay is silty, variegated, mottled and coloured red brown, yellow or white (Brown and Stephenson, 1991). Lawson (1992) suggested that the proportion of sand in this formation is highly variable, but typically in the range of 10 - 30%. The geology of the Shepparton Formation is extremely complicated due to the prior stream deposition, which resulted in localised deposits of coarse grade sands and better connection to deeper aquifers at some places. Due to the discontinuous nature of the Shepparton sand lenses the average horizontal hydraulic conductivity is around 2-3 m/day, but may be as high as 25-100 m/day in sandier parts (Prathapar et al., 1997). Depending upon the frequency of occurrence of prior streams the Shepparton Formation has been subdivided into two layers, the Upper Shepparton (US) with a greater frequency of prior streams and the Lower Shepparton, (LS) (Prathapar et al, 1997).
3 Regional Groundwater Model

Enever (1999) developed a regional groundwater model for the CIA using USGS MODFLOW (McDonald and Harbaugh, 1988) under PMWIN pre and post processing environment (Chiang and Kinzelbach, 1996). The layout of the finite difference grid used for the CIA model is shown in Figure 4.

Figure 4. CIA groundwater model description

The grid consists of 60 columns x 66 rows (1.25 km square mesh) and encompasses an area of 6188 km². The eastern edge of the model grid runs parallel to the bedrock. The southern edge is positioned to include Yanco Creek. The northern edge of the grid is positioned far enough north of the Murrumbidgee river to include the river and the areas around Darlington Point to account for groundwater pumping in these areas. The western edge of the grid is set several kilometers away from the western limit of the CIA to minimise effects of boundary conditions on the groundwater regime in the CIA.

The CIA model consists of four layers represented by the stratigraphic breakdown shown in Figure 4. Initial estimates of hydraulic properties in different layers are
taken from the equivalent formations in the Lower Murrumbidgee model (Punthakey et al. 1994). The interactions between model layers are specified using vertical leakance terms of MODFLOW. Vertical:horizontal anisotropy ratios of 1:20 to 1:100 are being used to calculate vertical hydraulic conductivities. The vertical leakance for each cell is calculated from vertical hydraulic conductivities and layer thicknesses as described in McDonald and Harbaugh (1988). Kriging is used in the interpolation of all spatial data sets in the CIA model using Surfer (Golden Software, 1994).

The 10 year model simulation period from March 1985 to March 1995 is divided into 120 equal stress periods of 1 month each. Each monthly stress period is further subdivided into 3 equal time steps of 10 days each.

Specified head boundaries for the CIA model (Figure 4) have been defined using the general head boundary package, GHB1. Initial piezometric levels in different layers for March 1985 were generated using the Department of Land and Water Conservation (DLWC) bore records.

DLWC data on monthly pumping rates and bore locations was used to specify pumping rates in the model. The recharge rate for each cell was initially set at a constant rate for 1985 to 1990 and another constant rate for the period 1990 to 1995. The recharge was calibrated during model simulation by trial and error procedures.

Enever (1999) used a trial and error procedure to calibrate the hydraulic parameters and recharge to match piezometric water level hydrographs at a number of locations. Enever (1999) reports good spatial correspondence between observed and model calculated spatial head distribution. The spatial correlation is best in the upper Shepparton layer and the ability to replicate spatial distribution of head decreases with depth. The dynamic or temporal correspondence between observed and calculated heads were evaluated as a test of calibration of the CIA model at 43 piezometers, 14 in the Upper Shepparton, 12 in the Lower Shepparton, 8 in the Calivil and 9 in the Renmark. Two typical results of calibration are shown in Figure 5 and Figure 6. From these and other calibration results of Enever (1999) it is observed that model results follow the overall trend of the observed piezometric levels but do not properly represent the seasonal variation of piezometric levels. This was attributed to high
specific storage values for confined layers. As model calibration is an ongoing process it was revisited and refined for some piezometers. This is discussed in the next section.

Figure 5. Observed and calculated hydrographs: Piezometer GW030349_1 Model Layer = Upper Shepparton. Piezometer location = Easting 383100(m) Northing 6176150(m)

Figure 6. Observed and calculated hydrographs: Piezometer GW030389_2 Model Layer = Renmark. Piezometer location = Easting 416487(m) Northing 6167017(m)
3.1 Recalibration of the CIA model

As the regional groundwater model of the CIA is not designed to simulate the detailed processes of capillary upflow and evapotranspiration (ET), it cannot predict the salinity changes in the top layer i.e. Upper Shepparton. Further calibration cannot improve the prediction of salinity changes in the Shepparton layer, because of the non representation of driving processes i.e. capillary upflow and ET. Due to prior stream activities, the geology of the upper and lower Shepparton layers is too complex to improve by calibration. Moreover previous studies (Enever, 1999, Lawson, 1992) have shown that the connection between shallow and deep aquifers is not good. Therefore it was decided that to predict the head and salinity changes in deeper layers due to pumping from deeper layer, it was not critical to improve the calibration of shallow i.e. upper and lower Shepparton layers. Table 1 shows the location of six piezometers selected for recalibration. Improvement in the hydrographs was achieved by adjusting the input pumping well file and the leakance between the Lower Shepparton and Calivil aquifers and storage coefficients in the Calivil and Renmark aquifers.

Table 1. Piezometers selected for recalibration.

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Layer</th>
<th>Piezometer number</th>
<th>Easting (m)</th>
<th>Northing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calivil</td>
<td>GW030414_1</td>
<td>404500</td>
<td>6167760</td>
</tr>
<tr>
<td>2</td>
<td>Calivil</td>
<td>GW030589_3</td>
<td>416487</td>
<td>6167017</td>
</tr>
<tr>
<td>3</td>
<td>Calivil</td>
<td>GW036366_2</td>
<td>390555</td>
<td>6177750</td>
</tr>
<tr>
<td>4</td>
<td>Calivil</td>
<td>GW030282_2</td>
<td>429180</td>
<td>6161900</td>
</tr>
<tr>
<td>5</td>
<td>Calivil</td>
<td>GW036040_2</td>
<td>385190</td>
<td>6141650</td>
</tr>
<tr>
<td>6</td>
<td>Calivil</td>
<td>GW036367_2</td>
<td>423087</td>
<td>6171525</td>
</tr>
</tbody>
</table>

Figure 7 to Figure 12 show the hydrographs pertaining to the old and new calibrations. It is evident from these results that though some piezometers (GW030282_2 and GW036040_2) do not reflect seasonal variations fully, there is a marked improvement in match between observed and calibrated heads in all of them.
Figure 7. Piezometer GW030341_1, Calivil Layer

Figure 8. Piezometer GW030489_2, Calivil Layer

Figure 9. Piezometer GW036366_2, Calivil Layer
3.2 Solute transport model development

The PMWIN processing environment (Chiang and Kinzelbach, 1996) facilitates solute transport model development. A solute transport simulator, MT3D (Zheng, 1990) is
included in PMWIN along with the groundwater flow simulator MODFLOW (McDonald and Harbaugh, 1988). MT3D (Zheng, 1990) takes head distribution solutions from MODFLOW and uses them to calculate solute transport through advection and dispersion. The MT3D model development requires specification of the boundary and initial conditions for solute transport and parameters for advection and dispersion. The other parameters/stresses are automatically taken from MODLOW by PMWIN. The dispersion parameters to be specified are longitudinal and transverse dispersivity. This is normally specified as horizontal longitudinal dispersivity and ratios of horizontal longitudinal dispersivity to horizontal and vertical transverse dispersivities. To specify the boundary and initial conditions for solute transport the groundwater salinity data were collected and analyzed, which is given in the following section.

3.2.1 Salinity data collection and analysis

Past water salinity data of the modeled area were collected from the offices of CIC and DLWC at Leeton and Griffith. Most of the data were in hard form in salinity registers, which had to be entered into computer. Though salinity records from 1973 onwards and even earlier were found, they were temporally and spatially scattered. For the early salinity data there was in many cases no record of sampling date and salinity data of up to five years were lumped together in many cases, for example 'salinity between 1975-1980.' Also the same piezometers had not been consistently sampled and many data entry errors were encountered. Another technical deficiency in the salinity data was that salinity records did not have layer tags associated with them, so as to identify which layer (out of 4 layers in the model) a particular record belonged to. This was overcome by developing a computer program in ‘C’ to assign layers to salinity records. The program took depth to the bottom/top of layers information from the groundwater model and depth to the screen of the piezometers from the salinity records and assigned the layers accordingly. Thus salinity data were processed and analyzed to get spatial and temporal trends in water salinity. In view of these limitations in the salinity data the results should be interpreted cautiously, only broad observations on salinity trends should be made.
• **Upper Shepparton (US) salinity**

It is evident from the salinity trends in Figures 13 to 17 that salinity has gradually increased in the US layer. In 1973, except for a few areas (for which data is not reliable enough to exclude the probability of error), the salinity in most of the CIA was less than 4 dS/m (4000 EC). By 1987 considerable area in the southern district of the CIA had salinity levels up to 16 dS/m (16,000 EC). This is after neglecting isolated pockets of very high salinity, 24 dS/m (24,000 EC). Surprisingly the salinity in 1987 is lower than 1984. This may not be real as different sets of piezometers were sampled at the two dates. The overall increase in salinity in the US is essentially the product of irrigation induced water table rise. The water table in the CIA has risen at a rate of up to 1m per year until the late 1980’s, which is reflected in the increased salinity. As already discussed there are errors and gaps in data resulting in white patches and isolated bulls eyes in the salinity plot. In spite of this the salinity data should reflect the overall trends. The presence of isolated high salinity pockets in the field are more likely in recent data than in the very old data as salinity has been increasing due to prolonged shallow water tables.

**Figure 13. Salinity (EC) in US 1973**
Figure 17. Salinity (EC) in US 1987

- Lower Shepparton salinity

The salinity trend for the LS in Figure 18 to Figure 21 shows that as in US, the salinity has gradually increased in the LS layer. In 1973 the majority of the CIA had salinity less than 4 dS/m (4000 EC), which increased up to 8 dS/m (8000 EC) over more than half of the CIA with some small areas up to 12 dS/m (12,000 EC). The increase in salinity in the LS is also due to the rise in water tables.

Figure 18. Salinity (EC) in LS 1973
Figure 19. Salinity (EC) in LS 1978

Figure 20. Salinity (EC) in LS 1984

Figure 21. Salinity (EC) in LS 1987
• Calivil salinity

From Figures 22 to 25 it appears that initially there was a trend of increasing salinity from the northwest to southeast, which changed to a northeast to southwest trend. It also appears that salinity generally has decreased from a maximum of around 1.9 dS/m (1900 EC) at the southeast tip in early years to a maximum of 1 dS/m (1000 EC) at the western edge of the CIA. However, samples for the Calivil aquifer are few and not evenly distributed spatially or temporally (only 2 to 3 yearly data points in the entire model domain). To overcome this the data were lumped into 5 year periods. This method was adopted to assist in Kriging. This reduces confidence in the early salinity data for the Calivil. There does not appear to be a valid hydrogeological reason for any decrease in the salinity. Therefore, the decrease in the salinity is attributed to the lack of data at the same locations. Recent data much more reliable. The spatial salinity trend in recent data is an increase from the northeast to southwest, following the general direction of groundwater flow. A safe assumption from the recent data is that compared to the shallow layers, the water quality in the Calivil is very good, around 0.7 dS/m (700 EC), and has not changed much over recent time.

Figure 22. Salinity (EC) in Calivil 1976
Figure 23. Salinity (EC) in Calivil 1979

Figure 24. Salinity (EC) in Calivil 1982

Figure 25. Salinity (EC) in Calivil 1985
Renmark salinity

Figures 26 to 29 show the salinity trends in the Renmark layer. The temporal and spatial trends in salinity in the Renmark aquifer closely resembles that of the Calivil. Here also a reduction in salinity over the period 1976-1985 is suggested, which is more due to the data gaps than any physical reason. The recent spatial trend in the salinity is an increase from the northeast to southwest, which is broadly aligned with the ground water flow direction. The reason for spatial similarity in the salinity trends between Calivil and Renmark is the good hydraulic connection between these two layers. The 1985 salinity level in the Renmark layer, < 0.65 dS/m (< 650 EC), is lower than that of the Calivil aquifer.

Thus groundwater in the deeper layers i.e. Calivil and Renmark is a good resource, which can be tapped to augment the surface water supplies for irrigation. As a management tool in decision-making about how to use this resource sustainably, one needs to know the system responses to the imposed stresses in the form of groundwater pumping. The groundwater and solute transport models predict system responses. This report describes the development of a combined groundwater flow and solute transport model in the next sections.

Figure 26. Salinity (EC) in Renmark 1976
Figure 27. Salinity (EC) in Renmark 1979

Figure 28. Salinity (EC) in Renmark 1982

Figure 29. Salinity (EC) in Renmark 1985
3.2.2 Boundary and initial conditions for the solute transport model

Constant concentration boundaries were defined and aligned along the general head boundaries (GHB) for the flow model (Figure 4), as the salinity analysis showed that concentration does not change along the boundaries, which are set far beyond the irrigation area. The related physical reason behind this choice is the process of salinity change. The choice of constant concentration boundary is justified along the boundaries of the flow model, as these regions have not experienced appreciable water table changes, which cause salinity change (increase).

As the flow model has been developed and calibrated for the period March 1985-March 1995, the March 1985 salinity was chosen as the initial conditions for the solute transport model. The initial conditions for all layers were generated by Krigging the 1985 salinity data by the SURFER (Golden Software, 1994) software. As previously discussed the quality and quantity of the salinity data were not satisfactory. In the shallow layers (US and LS) sufficient data were available inside the irrigation area but data outside the irrigation area were rather limited, as can be seen in Figure 30.

Figure 30. Piezometers sampled for salinity in US, 1984

For Krigging to be satisfactory one needs data to be evenly distributed. Because of little data outside the irrigation area Krigging generated some negative values in some cells. This problem was overcome by introducing some artificial data points in the
vicinity of known data points by approximate interpolation, to produce the initial conditions shown in Figure 31 and Figure 32.

**Figure 31. Model initial conditions of salinity (EC) in US, 1985**

![Figure 31. Model initial conditions of salinity (EC) in US, 1985](image)

**Figure 32. Model initial conditions of salinity (EC) in LS, 1985**

![Figure 32. Model initial conditions of salinity (EC) in LS, 1985](image)

For deeper layers, Calivil and Renmark, very few data points, mainly outside the CIA were available, Figure 33.
In addition to the quality of salinity data was a concern for the deeper layers. One erroneous data point can make a huge difference to the salinity distribution. For example by removing one high value from the salinity data set for the Calivil layer in 1995 the salinity distribution is changed significantly from that in Figure 34 to that in Figure 35.
Figure 35. Salinity (EC) data for the Calivil with the erroneous value removed, 1995 data

Due to the limited data availability the data in the deeper layers data 1979 to 1985 were combined and exceptionally high values removed to generate a satisfactory distribution of salinity in the Calivil and Renmark layers, Figure 36 and Figure 37.

Figure 36. Model initial conditions of salinity (EC) in the Calivil, 1985
3.2.3 Solute transport model parameters

Development of a solute transport MT3D (Zheng, 1990) model in the PMWIN (Chiang and Kinzelbach, 1996) processing environment requires specification of boundary and initial conditions and specification of solute transport parameters only. Values of solute transport parameters e.g. horizontal longitudinal dispersivities and the ratio of transverse horizontal and vertical dispersivities to the horizontal dispersivity, adopted in the solute transport model, are shown in the Table 2. The ratios used are commonly used in the literature and the value of longitudinal dispersivity is generally applicable to the area (Pers. comm., Khan, 2000).

Table 2. Parameters for the solute transport model.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Longitudinal dispersivity (m)</th>
<th>Horizontal transverse dispersivity/longitudinal dispersivity</th>
<th>Vertical transverse dispersivity/longitudinal dispersivity</th>
<th>Molecular diffusion coefficient (m²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>0.1</td>
<td>0.08</td>
<td>$1 \times 10^{-9}$</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>0.1</td>
<td>0.08</td>
<td>$1 \times 10^{-9}$</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>0.1</td>
<td>0.08</td>
<td>$1 \times 10^{-9}$</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>0.1</td>
<td>0.08</td>
<td>$1 \times 10^{-9}$</td>
</tr>
</tbody>
</table>
3.2.4 Solute transport model run, calibration and sensibility study

The solute transport model was run for the period March 1985-March 1995. Figure 38 to Figure 41 show the model generated concentration distribution at the end of the 10 year simulation period (1995).

Figure 38. Model generated salinity (EC) in the US for 1995

Figure 39. Model generated salinity (EC) in the LS for 1995
There are not sufficient data available in any layer to generate the spatial distribution for all layers for any year. So the results can only be discussed in terms of sensibility. By sensibility we mean an analysis that indicates whether or not the solute transport model solutions are reasonable based on our understanding of the key processes. Sensibility analysis was carried out by finding out the concentration difference in each layer in the periods 1985-1995 and 1990-1995. It is observed from the results for the
US that whereas the majority of the area outside the CIA has experienced a concentration change between –1 dS/m to +1 dS/m (-1000 to +1000 EC), the majority of area in the CIA has experienced a decrease in the salinity, Figure 42 and Figure 43. The salinity changes during the period 1985-1995 (Figure 42) are greater than those that occurred during the period 1990-1995 (Figure 43). This is what would be expected under initially high recharge conditions that then reduce.

Figure 42. Modeled salinity (EC) change in the US between 1985 and 1995
The decrease in salinity, though not consistent with the physical reality, is not surprising. This model does not include the processes that are responsible for salinity changes (generally increase) in the US, i.e. capillary uptake and ET. Only a model like SWAGMAN Destiny or FEMWATER (Khan, 2000) can simulate these processes in detail and hence can correctly predict salinity changes in the US. However, the simulated salinity changes in the US are consistent with the recharge and discharge processes simulated by the model. The initial salinity is already high within the CIA; thus any recharge from the surface that is of a lesser salinity can only reduce the salinity in the layer. This is what appears to be occurring in the CIA.

Figure 44 and Figure 45 show the simulated salinity changes in the LS during 1985-1995 and 1990-1995 respectively. It is observed from these figures that for most of the area salinity has increased during the periods 1990-1995 and 1985-1995. The areas, where salinity decreases are smaller than the areas of salinity decrease for the US, and also the absolute reductions are smaller than in the US. This also suggests that the model solution is logical in that salinity is likely to gradually increase as salt leaks down from the US. The areas, where there are salinity decreases, are more likely to be due to high initial values in these areas than due to a poor representation of processes as, was the case for the US.
For the Calivil layer most of the area has experienced an increase in salinity during the period 1985-1995 except some areas near the boundaries, Figure 46. This is logical in that leakage of highly saline water from the LS will increase the Calivil salinity. This is consistent with a small increase in salinity in the Calivil in and around
the irrigation area between 1990 and 1995, Figure 47. The areas distant from the CIA show little change in salinity, thus the model trends of salinity appear sensible.

Figure 46. Modeled salinity (EC) change in the Calivil between 1985 and 1995

Figure 47. Modeled salinity (EC) change in the Calivil between 1990 and 1995

In the Renmark formation there is only a very small increase in salinity for the majority of the area between 1985 and 1995, Figure 48. Some areas near the
northeastern and eastern boundary even show some decrease in salinity. The initial values in these areas are quite high so the decrease is more due to numerical adjustment than any physical process. The negligible changes in salinity during the period 1990-1995 are consistent with the overall trend of a small increase, Figure 49. As the Renmark layer is the deepest layer, only small increases in salinity are consistent with the physical reality.

Figure 48. Modeled salinity (EC) change in the Renmark between 1985 and 1995
Thus the model results appear quite sensible for the Calivil and Renmark aquifers and generally reasonable for the LS. However, for the reasons discussed above salinity trends cannot be expected to be sensible in the US.

Adequate data of temporal changes in salinity were available for only two piezometers that were also used to establish model sensibility. Figure 50 and Figure 51 show the temporal variation of observed and simulated salinity at piezometer 405 in the Calivil and 36040 in the Renmark layers. It is observed from these figures that model predicted salinity variation is very close to the actual salinity variation. Though observed and simulated salinity in the Renmark layer are different in absolute numerical values, this is a very small amount (0.03 dS/m) and both lines are nearly parallel which show that the processes are adequately simulated. The actual numerical values vary because of the different initial values. These differ due to the interpolation process in establishing the initial data for each model cell.
Some salinity data at the Coleambally deep bore site are available between 1992-1995. These are plotted against salinity in the Calivil and Renmark layers at that site, Figure 52. The observed salinity variation is very close to the modeled trends in both layers, which are more or less parallel. The water discharging from the Coleambally bore is mainly a mixture of Calivil and Renmark water, therefore a salinity graph of the mixture will plot somewhere between the individual lines for the two layers. The
modeled salinity variation in that case will be even closer. If we ignore the difference in initial values due to interpolation, we find that modeled and observed salinity trends are quite similar.

Figure 52. Salinity (EC) modeled and observed at the Coleambally deep bore site, Renmark/Calivil layer

There is very little which can be gained or improved by running sensitivity analysis to the transport parameters like longitudinal and horizontal and vertical transverse dispersivities or molecular diffusion coefficients since the cell sizes are large. So no sensitivity analysis of the transport parameters was done. In the absence of adequate historical salinity data it was not possible to further verify or improve the solute transport model calibration. The solute transport model should be considered to be as well calibrated as the corresponding flow model, as there is little which can be improved by changes in the solute transport parameters. In view of solute transport model producing sensible results for deeper layers i.e., Calivil and Renmark, it can satisfactorily be used to predict the long term salinity trends, if not actual values arising out of possible pumping from deeper layers.
3.3 Pumping scenarios

The long term impacts of pumping from deeper aquifers on watertable levels in the US will determine whether or not deep groundwater pumping is a useful option to assist in long term watertable and hence salinity control. The aquifer conditions as stated earlier are such that there is a relatively poor connection between deep and shallow aquifers, which is typical of the Riverine plain. However, deep groundwater pumping may reduce watertables in areas where there is a good connection and may at least provide a somewhat increased downward movement of water generally, providing some opportunity for the leaching of salts from the upper layers.

Already around 46000 ML per year is pumped from the deeper aquifers in the modeled region. Most of this pumping is occurring in the northern part of the CIA. This volume includes approximately 6000 ML per year being pumped by the Coleambally deep bore in southwestern CIA. It is the central and southern parts of the CIA that are suffering from the highest watertables and which may benefit from pumping of the deeper aquifers. The CIA has an additional allocation of around 4000 ML per year from the deeper aquifers therefore scenarios were developed that targeted using this allocation in southern Coleambally to determine whether deep pumping will be beneficial in assisting watertable and salinity control.

The water pumped from the deep aquifers is expected to be of good quality, 0.5 – 0.7 dS/m (500 - 700 EC), and as such will be suitable for mixing with the existing surface water irrigation supplies. This is one of the key advantages of deep pumping that the use or disposal of the water is not difficult. In contrast should shallow pumping be undertaken from the LS or US the water will be highly saline and will require specialised disposal facilities e.g. evaporation basins with serial biological concentration schemes. An additional benefit of pumping from the deeper aquifers is that they underlie the whole area and are highly transmissive. By comparison the upper layers are a mix of clays and sands such that pumping would require a large number of individual low volume pumps.

The flow and solute transport models were run to evaluate several deep pumping scenarios with the aim of providing some drawdown in the US over central and
southern CIA. This requires a trade off in maximizing the drawdowns in the US whilst maintaining low water salinity from the bore. Also the instantaneous drawdown caused by pumping in the deeper layers must be controlled within reasonable limits. The flow and solute transport models were run for 20 years starting at 1995, with the new bore(s) introduced in August 2000 and running for the 8 months of the irrigation season, between August and March every year. This timing is to allow mixing of the pumped water with the irrigation supply.

Rather than using the modeled output of 1995 as the initial condition, actual piezometric heads and salinity were used to generate a set of initial conditions. This was done to avoid an accumulation of errors. The recharge cycle developed for 1985-1995 was repeated twice. This is based on the assumption that the aquifer system is at a new equilibrium and as such recharge is likely to remain similar. This assumption will not be valid if the climate or cropping regime changes drastically.

Pumping scenarios were developed with the aim of maximising drawdowns in the US whilst maintaining low bore discharge salinity and reasonable drawdowns in the pumping aquifers at the bore location. Six scenarios were developed with various bore locations in southern CIA, Figure 53, and Table 3.

Figure 53. Deep bore locations in CIA
Table 3. Bore locations

<table>
<thead>
<tr>
<th>Locality</th>
<th>Easting (m)</th>
<th>Northing (m)</th>
<th>Scenario number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>403848</td>
<td>6130805</td>
<td>1,2,5,6</td>
</tr>
<tr>
<td>B</td>
<td>411348</td>
<td>6132055</td>
<td>3,4</td>
</tr>
<tr>
<td>C</td>
<td>395098</td>
<td>6138305</td>
<td>5,6</td>
</tr>
</tbody>
</table>

For all scenarios the total pumping volume remained constant at 4000 ML per year, but the proportions from the Calivil and Renmark aquifers were varied, Table 4.

- Scenario 0 – no new bores, base condition for comparison with scenarios 1 to 6.

- Scenario 1 - one bore in the Calivil layer only in central southern CIA (location A.)

- Scenario 2 - one bore in same location as scenario 1, but pumping volume distributed between the Calivil and Renmark aquifers 30:70, to reduce drawdowns near the bore and maintain low discharge water salinity at location A.

- Scenarios 3 and 4 – the bore was located near the eastern boundary of the CIA (location B) in an attempt to create greater drawdown in the US as this area has better connection between deep and shallow aquifers. Scenarios 3 and 4 differed in the pumping distribution between the Calivil and Renmark aquifers.

- Scenarios 5 and 6 - two bores were used (locations A and C) to distribute drawdowns in the deeper aquifers over a wider area and maintain low discharge salinity. Each well pumped a total volume of 2000 ML per year. Scenarios 5 and 6 differ in the pumping distribution between the Calivil and Renmark aquifers.
### Table 4. Pumping scenarios

<table>
<thead>
<tr>
<th>Scenario number</th>
<th>No of new bores</th>
<th>Locality (Figure 54)</th>
<th>Total pumping (ML/year)</th>
<th>Calivil contribution (%)</th>
<th>Renmark contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>A</td>
<td>4000</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>A</td>
<td>4000</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>B</td>
<td>4000</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>B</td>
<td>4000</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>2*</td>
<td>A &amp; C</td>
<td>4000</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>6</td>
<td>2*</td>
<td>A &amp; C</td>
<td>4000</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

* Volumes equally divided between the two locations
4 Modeling Results

In order to evaluate the impact of these various pumping scenarios the ‘base case’ needed to be established. The base case was taken as the current level of pumping with no new bores. The model was run under the same conditions as stated earlier for 20 years to establish the changes over time without any new bores. In order to evaluate the impact of extra pumping most results are presented as the relative difference between the particular scenario and the base case. This is appropriate as we wish to understand the impact of the extra pumping and also the model is better used as a tool to analyse long term trends of drawdowns and salinity rather than absolute values.

The scenario results portray the important factors for conjunctive water use in a salinity control situation:

- The spatial distribution of the relative drawdown (Scenario minus base case) in all layers at the end of 5 and 15 years of pumping. This is to determine the effectiveness in the pumping at creating a drawdown in all layers. Special attention is given to the upper layer, as this will have greatest impact on watertable and salinity conditions at the surface.

- The relative heads (Scenario minus base case) at the bore location in the Calivil and Renmark layers. This is to determine the drawdowns at the pump site and whether such levels of pumping will be practically feasible.

- The temporal variation of salinity of the discharge water from the bore. This is was derived by determining the aquifer quality changes at the pumping site in the Calivil and Renmark aquifers and then deriving a mixed salinity according to the proportions of water derived from both layers. These values are plotted as the scenario value and the base case value rather than the difference between the two, because it is important to know the absolute value of the water salinity (for reuse purposes) as well as the change from base case induced by the pumping.
The following results are based on runs of a model that has considerable uncertainty in terms of hydrological properties of aquifers and as such the long term trends are considered, with less emphasis on the absolute values of head or salinity. Also during the modeling of long term pumping it was noticed that the boundary conditions in the southeastern section of the model probably require some adjustment. However, this did not have a major impact on the scenarios investigated.

### 4.1 Scenario 1

The relative head hydrograph in the Calivil (Figure 54) showed that there was an excessive drawdown (> 100 m) and the water salinity deteriorated rapidly (Figure 55). The magnitude of the drawdown was considered a physical impossibility, as this would have caused the well to run dry. This scenario was thus infeasible, indicating that any pumping would need to be split between the Calivil and Renmark layers. It also showed that the water salinity in the Calivil aquifer could rise sharply if pumping was excessive. This would be due to excessive leakage from the saline LS layer sitting directly on top of the Calivil aquifer. The relative drawdowns are not shown, as this scenario is not useful.

![Figure 54. Modeled temporal variation of head difference (S1-S0) in Calivil layer](image-url)
4.2 Scenario 2

The spatial distribution of drawdown in the Calivil and Renmark formations (Figure 56 to Figure 59) showed that almost the entire CIA will have a minimum relative drawdown of 0.2m.
Figure 57. Modeled difference in drawdown (S2-S0) in the Renmark after 15 years

Figure 58. Modeled difference in drawdown (S2-S0) in the Calivil after 5 years
The maximum relative drawdown at the well in these two layers may be between 30-38 meters. The drawdowns, however, in these layers are cyclic i.e. aquifers almost fully recover every year as shown by the hydrographs, Figure 60 and Figure 61. The residual drawdown in these layers is less than 2 m at the end of 15 years of pumping. This indicates that this level of pumping will not have a significant long term impact on the water availability in these aquifers.
The spatial distribution of drawdown in the LS and US are rather surprising Figure 62 to Figure 65. Rather than a maximum drawdown at the well location in the middle of the southern CIA, drawdowns in these two layers are greatest around the southeastern region of the CIA. The maximum drawdown in the southeastern CIA at the end of 15 years of pumping is 1 - 2 m. The reason for this uneven distribution of drawdown in the upper layers is that there are marked differences in the connectivity between the deep aquifers being pumped and the shallow aquifers. In the southeastern and southwestern regions of the CIA there are better hydraulic connections/conductivities between the deep and shallow layers than the middle of the southern CIA where the bore is located.

The drawdowns in the US are lower than LS, which is logical as the pumping is from the deep layers, drawdown effects will be reduced upwards. An order of magnitude difference in the drawdown between the deep and shallow aquifers shows that the hydraulic connection is generally poor between these two systems. Because of this there is quite a time lag in the development of drawdowns in the US. After 5 years (Figure 64) the drawdown is relatively limited, which then develops into quite a large area of impact after 15 years (Figure 65). The effect of deep pumping on the drawdown in the shallow aquifers is relatively small and has tremendous spatial variation. Thus the impact of deep pumping in this scenario on shallow watertables
may be considerable in some limited areas but is generally negligible. However, any additional drawdown and hence increased opportunity for water movement downward and hence salt leaching is useful.

Figure 62. Modeled difference in drawdown (S2-S0) in the LS after 5 years

Figure 63. Modeled difference in drawdown (S2-S0) in the LS after 15 years
The hydrograph at the bore site in the LS (Figure 66) shows that although there is a cyclical recovery of drawdown in the LS, the overall trend is an increasing residual drawdown with time. The maximum residual drawdown is about 0.4 m at the end of 15 years of pumping. There is no cyclic recovery in the bore site hydrograph for the
US (Figure 67). The residual drawdown in the US increases continuously with time reaching 0.2 m at the end of 15 years of pumping. These results show the extreme variability of the aquifer conditions in the CIA. At the pump site the residual drawdown is only about 0.2 m whereas at the southeastern edge of the CIA, some 11 km away there is a 1 – 2 m residual drawdown.

Figure 66. Modeled temporal variation of head difference (S2-S0) in LS layer

Figure 67. Modeled temporal variation of head difference (S2-S0) in US layer
The temporal variation of salinity in Figure 68 shows that the salinity of the discharge water will increase as a result of pumping. Interestingly the baseline salinity also shows an increasing trend due to the natural leakage and existing pumping causing salt migration from the upper layers. The relative increase in salinity compared to the base scenario is about 0.5 dS/m (500 EC), which equates to about 0.033 dS/m (33 EC) per year. The absolute value is around 1.3 dS/m (1300 EC) after 15 years, which is quite high for irrigation purposes. Assuming surface irrigation water available for mixing has a salinity of 0.2 dS/m (200 EC) and a threshold mixed irrigation water quality of 0.5 dS/m (500 EC) this would require about 11 000 ML of surface water for mixing. Given the availability of surface water for shandying, the increase may be acceptable. However, the salinity of the bore water is likely to continue to increase and the quality of the water for other users, who may not be shandying, would be degraded.

Figure 68. Modeled temporal variation of discharge water salinity (S2-S0) at the bore, location A. Mix of Renmark and Calivil

4.3 Scenario 3

In this scenario the pumping location is in the southeastern corner of the CIA. As such the maximum drawdowns in the Calivil and Renmark are in this area (Figure 69 and
Figure 70) leaving a significant area of the southwestern CIA with very little drawdown and hence very little potential for enhanced leakage from the upper layers. Also there is a considerable area of significant drawdown outside the southeastern boundary of the CIA, which is not helpful in trying to achieve some salinity control in the upper layers within the CIA.

**Figure 69. Modeled difference in drawdown (S3-S0) in the Renmark after 15 years**

![Renmark Drawdown Map](image)

**Figure 70. Modeled difference in drawdown (S3-S0) in the Calivil after 15 years**

![Calivil Drawdown Map](image)
The maximum relative drawdown at the bore in the Renmark layer is around 12 m, which is significantly lower than scenario 2 (~ 30 m), Figure 71. This may be influenced by the proximity of the General Head Boundary along the southern part of the model. The maximum relative drawdown in the Calivil formation is comparable with scenario 2 at around 38 meters, Figure 72. This result is to be expected as 100% of the abstraction is from the Calivil formation. This results in a smaller drawdown in the Renmark formation below. As in scenario 2 the drawdowns in these layers are cyclic i.e. aquifers recover during the non pumping period. The residual drawdown in these layers is less than 2 m at the end of 15 years of pumping.

Figure 71. Modeled temporal variation of head difference (S3-S0) in Renmark layer at the bore site
The drawdowns in the LS and US are also concentrated around the eastern boundary of the CIA, Figures 73 and 74. The maximum drawdown in this area at the end of 15 years of pumping is between 2-5 m, which is greater than found in scenario 2. This is due to higher hydraulic conductivities and hence better hydraulic connection between deep and shallower aquifers in that part of the CIA. However, the area of drawdown is confined to the eastern boundary with a significant area outside the CIA, and there is very little impact elsewhere in the CIA.

Figure 73. Modeled difference in drawdown (S3-S0) in the LS after 15 years
The hydrographs at the well site in the US (Figure 75) show an overall trend of increasing residual drawdowns. The maximum residual drawdown in US and LS at the end of 15 years of pumping is around 3.5 m. Although confined to a smaller area near the bore this is a significant level of drawdown which will probably have a significant effect in improving salinity control in those areas. This scenario will be beneficial for the small areas that experience large drawdowns, however it will not have a significant impact over the large areas that need salinity control.
Figure 76 shows that the salinity of water from the bore will increase by around 0.45 dS/m (450 EC) after 15 years of pumping to about 1.4 dS/m (1400 EC), a moderate increase rate of around 0.03 dS/m (30 EC) per year. This may be acceptable given the availability of surface water for shandying, however the salinity of the water is likely to continue to increase into the future. This increase may be due to the 100% abstraction from the Calivil and reducing this is explored in scenario 4.

**Figure 76. Modeled temporal variation of discharge water salinity (S3-S0) at the bore, location B. Calivil only**

![Graph showing modeled temporal variation of discharge water salinity](image)

### 4.4 Scenario 4

The bore position for scenarios 4 and 3 are the same, the only difference is that abstraction is equally split between the Renmark and Calivil. Thus the overall results are similar, however, the area of maximum drawdown near the bore in the Renmark is larger for scenario 4 than scenario 3. The maximum relative drawdown is also larger for the Renmark (~17 m) than in scenario 3 (~12 m). For the Calivil layer, the maximum relative drawdown is smaller (~25 m) than in scenario 3 (~38 m). The residual drawdowns, however, in both scenarios in both these layers are comparable. As in scenario 3 much of the induced drawdown is outside the CIA, which is non beneficial from a salinity control perspective.
The area of drawdown in both the LS and US are slightly reduced in this scenario compared with scenario 3. The residual drawdown in both LS and US are also reduced as compared to the scenario 3. This is due to the decrease in pumping from the Calivil and hence reduced drawdowns that result in less leakage from the upper layers.

The water salinity from the bore after 15 years is about 1 dS/m (1000 EC) (Figure 77), a net increase of about 0.2 dS/m (200 EC). Splitting the pumping between the Renmark and Calivil formation has improved the water quality, since there is less leakage from the more saline upper layers. Thus it appears that there is a trade off between maintaining the bore water quality for conjunctive use and maximising drawdowns in the upper layers.

**Figure 77. Modeled temporal variation of salinity (S4-S0) at the bore, location B.**

4.5 **Scenario 5**

In order to obtain a more even distribution of drawdown in the deeper layers under the southern portion of the CIA both scenario 5 and 6 use two pumps, one in the middle of the southern portion of the CIA and one towards the west of the CIA. The Calivil and Renmark layers show a minimum relative drawdown of 2 – 5m over almost the
entire southern portion of the CIA, Figures 78 and 79. The spatial distribution of drawdown in the two deeper layers is like an ellipse with the two wells at its foci.

Figure 78. Modeled difference in drawdown (S5-S0) in the Renmark after 15 years

Figure 79. Modeled difference in drawdown (S5-S0) in the Calivil after 15 years
The maximum relative drawdown at bore location A in these layers is about 17 - 20 m (Figure 80 and Figure 81) and at bore location C is about 11 - 22 m (Figure 82 and Figure 83). The drawdowns in these layers follow the annual pumping cycle, with residual drawdowns at both locations less than 1.5 m after 15 years of pumping.

Figure 80. Modeled temporal variation of head difference (S5-S0) in Renmark layer, location A

![Graph showing modeled temporal variation of head difference in Renmark layer, location A.]

Figure 81. Modeled temporal variation of head difference (S5-S0) in Calivil layer, location A

![Graph showing modeled temporal variation of head difference in Calivil layer, location A.]
The spatial distribution of drawdown in the LS and US is concentrated away from the bore locations, Figure 84 and Figure 85. Rather the maximum drawdown in the US is on the eastern boundary of the CIA and areas on the western and southwestern boundary. A large area directly between the two bore locations does not show any drawdown in the US. This reflects the level of connectivity between the deep and
shallow aquifers. A large drawdown is induced across the whole of the southern portion of the CIA in the Renmark and Calivil, but this does not result in an even drawdown in the upper layers. The complex nature of these upper layers makes it difficult to predict where drawdowns will occur, however the widespread drawdown in the deeper aquifers give the opportunity for leakage and drawdown in the upper layers where good connections between deep and shallow layers exist. Figure 86 and Figure 87 show the drawdowns at the bore locations for the US.

Figure 84. Modeled difference in drawdown (S5-S0) in the LS after 15 years
Figure 85. Modeled difference in drawdown (S5-S0) in the US after 15 years

Figure 86. Modeled temporal variation of head difference (S5-S0) in US layer, location A
The water salinity after 15 years of pumping at both bore locations will reach about 1 dS/m (1000 EC) (Figure 88 and Figure 89), a net increase of around 0.2 dS/m (200 EC). This is very small at about 0.013 dS/m (13 EC) per year.
Figure 89. Modeled temporal variation of discharge water salinity (S5-S0) at the bore, location C. Mix of Renmark and Calivil.

4.6 Scenario 6

Scenario 6 only varies from scenario 5 in that Calivil:Renmark abstraction is 50:50 rather than 70:30. Thus the results of scenario 6 are very similar to those of scenario 5. However, there are some minor differences such as the maximum drawdown near both bores decreases in the Renmark and increases in the Calivil in scenario 6 as compared to scenario 5. The maximum relative drawdown also decreases in the Renmark and increases at both bore locations in the Calivil in scenario 6 as compared to scenario 5. The residual drawdowns, however, in both scenarios in both these layers are very similar. The relative drawdown in both LS and US are almost identical to those of the. There is a small increase in residual drawdowns in both LS and US at both bore locations as compared to scenario 5. These small differences indicate that greater pumping from the Calivil formation does not result in greater drawdowns in the upper layers, rather this is controlled by the degree of connectivity between the layers.

The changing in pumping mix has a significant impact on the bore water salinity, leading to a 0.6 dS/m and 0.45 dS/m (600 EC and 450 EC) increase at bore locations
A and C respectively, Figure 90 and Figure 91. This increasing salinity results from the greater abstraction from the Calivil that interfaces with the much more saline LS.

Figure 90. Modeled temporal variation of salinity (S6-S0) at the bore, location A. Mix of Renmark and Calivil.

Figure 91. Modeled temporal variation of salinity (S6-S0) at the bore, location C. Mix of Renmark and Calivil.
5 Discussion

Where conjunctive water use from deep bore pumping is considered for salinity control there are three key factors to be considered:

- The level of groundwater drawdown or salinity control in the rootzone that can be achieved;
- The salinity of the pumped water that is to be conjunctively used; and
- The long term aquifer water salinity

This modeling exercise has shown that depending upon the positioning of the pumps and from which layers pumping occurs that these factors can vary markedly.

5.1 US drawdowns

Hydrographs of the US show that drawdowns continuously increase with time i.e. drawdowns at the end of the 15 year pumping period are cumulative values. Thus an approximate analysis of the US drawdown for various scenarios is possible by comparing drawdown values after 15 years of pumping. The average drawdown experienced by an area covered by certain selected minimum values (0.2, 0.4, 0.6, 0.8 and 1 m) of drawdown were calculated for all scenarios, Figure 92. It is evident that in all scenarios there is a large area that has a resulting average drawdown in excess of 0.2 m after 15 years of pumping. In annual terms this is in effect 13 mm per year. The differences between scenarios are not that great, scenarios 2, 5 and 6 have a more widespread drawdown but scenarios 3 and 4 have a larger drawdown over a smaller area.

In interpreting these results it should be remembered that the LS and US are known to be highly variable in terms of thickness and hydraulic conductivity. However, where and how this variation occurs and the connection with deeper aquifers is not well understood. Also, this variation can occur over hundreds of meters and as such cannot be accurately reflected in this model, which has cell sizes of 1.25 x 1.25 km.
In all scenarios large drawdowns (10 to 20 m) were induced across a large portion of the southern CIA in the Renmark and Calivil, but this does not result in an even drawdown in the upper layers. This is likely to be the case but the degree to which this variation in drawdown will occur and prediction of where this will occur and to what extent cannot be accurately predicted by this model.

In the present model the processes in the unconfined aquifer are not accurately modeled, e.g. plant water uptake nor are the local scale processes in the unsaturated zone such as channel leakage and irrigation bay recharge represented. As such the drawdowns predicted in the US and to some extent the LS should be considered more as an indicator of enhanced leakage from these layers rather than any actual physically measurable decrease in watertables. Whether a decrease in watertables actually occurs, as a result of deep pumping, will depend upon local factors such as irrigation practice, cropping, rainfall, channel leakage and soil characteristics.

From the analysis of drawdowns it is possible to estimate the volume of water that has been removed from the US, the change in storage, compared to the base scenario. For each model cell the residual drawdown after 15 years was taken and multiplied by the
porosity for the US in that cell. This gives an estimate of the volume change in storage, which can be used to give an indication of the impact of deep pumping in enhancing leakage from the US to the deeper layers.

Figure 93 shows the resulting extra depth of water that has been removed from the US due to the deep pumping for each scenario. It can be seen that scenarios 3 and 4, which had the bore at the eastern edge of the CIA, have the largest change in storage. Scenario 2 had less change but spread over a wider area and scenarios 5 and 6 had still lower amounts spread over a still wider area. The maximum change in storage was about 0.17 m; this equates to an annual amount of 11 mm. The CIA Land and Water Management Plan assesses the average deep leakage over the area to be about 30 mm per year, so this 11 mm represents a significant increase in water removal from the US by deep leakage. However, an average value for scenarios 5 and 6 would be about 0.05 m, representing about 3 mm per year. This is only a 10% increase on the existing leakage to the deeper layers.

Figure 93. Extra water removed from US by deep pumping

This small amount of leakage is unlikely to have a significant impact on existing salinity problems. However, maintaining and enhancing the current deep leakage should assist with salinity control in combination with other measures. As stated above the distribution of the leakage across the landscape is uncertain, as the spatial
connection between the deep and shallow aquifers is not well known. The deep pumping however will cause drawdowns across large areas of southern CIA, especially with scenarios 5 and 6 and as such this will provide the opportunity for leakage to occur from the upper. The amount of leakage that will occur will depend upon the local geology and the impact it has on the sustainability of farming will depend upon many other factors as stated previously.

The volume of deep pumping required to create a widespread drawdown in the deeper layers across the southern portion of the CIA was 4000 ML per year. After 15 years of pumping this created a 2 – 5 m net residual drawdown over about 50,000 ha. This is 8mm of abstraction per ha per year. In those terms it can be seen that for a relatively small amount of pumping a large area can be affected.

The results of deep groundwater pumping on the shallow layers are not immediate. In all the scenarios there was a significant difference in the areas affected by drawdowns in the US in year 5 of pumping compared to year 15 of pumping. This means that using deep groundwater pumping to assist in salinity control is a long-term exercise the full benefits of which will not become apparent for many years. This modeling has clearly shown this and indicates that two or three years of monitoring of deep pumping installations are not adequate to gauge the full impact. It appears that deep pumping is best suited as a long-term preventative or stabilisation measure. In terms of salinity control it could be seen as a strategic response that will not in itself prevent or solve surface salinity, but will improve the overall prospects for the success of other measures to provide long term sustainability.

Since deep groundwater pumping will not have an immediate effect, for adequate salinity control in the root zone and reclamation of already salinised areas, shallow groundwater pumping (Shepparton formation) is more likely to be successful. However, this has the twin difficulties of a relatively impermeable shallow formation and very saline shallow groundwater.
5.2 Groundwater salinity

The advantage of deep pumping is that the water quality is good and thus can be conjunctively used with the non saline surface supplies. The volume of water that needs to be pumped to have a widespread impact is relatively small and as such there is little difficulty in mixing the groundwater with surface water supplies to achieve a negligible increase in the supply water salinity. In most scenarios there was only a small increase in the bore water salinity over the 15 year pumping period, such that continued conjunctive use would not be difficult. Only in scenario 4, bore on the eastern edge of the CIA with all the pumping from the Calivil, did the bore water salinity increase significantly, but still of a level that it could easily be shandied to acceptable quality. This scenario had the bore located in an area with higher hydraulic conductivities in the LS and US and as such a reasonable connection with the deeper layers. Also all the pumping was from the Calivil that interfaces with the saline surface formations and thus greater leakage was induced from the upper layers.

This is clearly a difficulty in using deep groundwater pumping for salinity control. There is a tradeoff between the advantage of creating some downward leakage and hence improved salinity control at the surface and an inevitable increase in the deep aquifer salinity due to that leakage moving salts downward. This tradeoff needs to be carefully managed.

Apart from scenario 2 the other scenarios had minimal increase in the bore water salinity, mainly because the bores were sited in areas where there was not a good connection with the surface layers directly around the bore site and that pumping was split between the Calivil and Renmark.

5.3 Aquifer salinity

One constraint with deep pumping for conjunctive use is that the groundwater salinity needs to be controlled so that the pumped water can continue to be used conjunctively with surface waters. However, another constraint is to ensure that the aquifer salinity
does not become degraded generally. This is important to protect the resource base for future users who may not be able to use the water conjunctively with other waters.

In order to assess the spatial change in aquifer salinity the final aquifer salinity after 15 years of pumping in scenario 5 was compared with the base case. The results show that after 5 years of pumping there is no change greater than 0.05 dS/m (50 EC) in the Renmark or Calivil. After 15 years of pumping the maximum increase in Renmark salinity is between 0.1 – 0.2 dS/m (100 - 200 EC), and confined to the areas very close to the bores (Figure 94), within 2.5 km, beyond these areas the maximum change is 0.05 dS/m (50 EC). In the Calivil there is no change after 5 years but after 15 years pumping the salinity increase is more widespread than in the Renmark layer and magnitude of increase is also higher, (Figure 95). The maximum salinity increase close to the well (within 2.5 km) is about 1 dS/m (1000 EC). Up to 6.5 km from the well changes of 0.1 – 0.2 dS/m (100-200 EC) may be expected.

**Figure 94. Change in salinity (EC) in the Renmark layer (S5-S0) after 15 years**
Overall these results show that this level of pumping over a long time frame (15 years) will have minimal impact on the general aquifer salinity. Thus the trade off between improving prospects for salinity control in the surface layers and degradation of the aquifer quality seem to be well balanced, at least for the short term.
This analysis of the potential for deep groundwater pumping in the Riverine plain for salinity control and conjunctive water use indicates that:

- Deep pumping can create widespread drawdowns in the deeper aquifers for relatively small pumped volumes.

- Drawdowns in the deep aquifers are not translated into equivalent drawdowns in the shallow formations either spatially or temporally. The low hydraulic conductivity of the surface formation generally results in small drawdowns with some larger drawdowns in small areas. The greatest drawdowns in the surface formations will not necessarily be at the pump site. Overall a significant area (30 – 40,000 ha) can be affected to provide an increase in leakage rates of 10 – 20% by a small number of pump sites extracting relatively small volumes of water.

- There is a considerable time lag in the creation of drawdowns in the upper layers. The deeper layers respond almost instantaneously but drawdowns in the upper formations may take 15 years or more of pumping to sufficiently develop.

- The relatively small, but widespread, drawdowns generated in the surface formation and the time lag in pressure response in the surface layers indicates that deep groundwater pumping for salinity control is a long term strategic measure. Deep groundwater pumping will not be a solution to surface salinity problems in itself but will provide long-term support for other more localised measures. In this it is likely to be useful if viewed as a preventative/stabilising tool.

- Conjunctive water use of surface water and groundwaters with deep groundwater pumping will be effective due to the low salinity and small volumes of groundwater.

- In using deep groundwater pumping to assist in surface salinity control there is an inevitable long-term increase in the deep aquifer water salinity due to leakage of the more saline surface water downward. This tradeoff between aquifer salinity
and surface salinity control benefit is key to the usefulness of deep groundwater pumping. Results of this modeling show that low levels of pumping, with the pump sited in areas of locally poor surface connection will result in small increases in aquifer salinity in the long term. Thus as a conjunctive water use tool deep groundwater pumping in irrigation areas is likely to have a long-term future. The usefulness of this water for single use as irrigation water will become reduced over time, however for irrigated areas this is less of an issue due to the surface supplies available for mixing.

- Deep groundwater pumping for salinity control in irrigation areas can be used as a strategic complementary tool to other measures with minimal impact on surface or groundwater quality.

- Any pumping implementation would need to closely monitor both aquifer and pumped bore water salinity to ensure that the resource does not rapidly degrade. Monitoring for potential benefits of surface salinity changes will be difficult as changes will be small. A monitoring program would need to be well planned and long term. The results of the modeling can assist with this.
7 References


Khan, S., 2000. Personal communication. CSIRO Land and Water, Griffith, NSW, 2680


